Department of the Navy
Office of Naval Research
Contract N6onr-24424
Project NR 234-001

WATER TUNNEL EXPERIMENTS ON SPHERES IN CAVITY FLOW

En-Yun Hsu and Byrne Perry

Hydrodynamics Laboratory
California Institute of Technology
Pasadena, California

Report No. E-24.9

April, 1954

Introduction

A program of experimental work on air-supported cavity flow has been in progress in the Free Surface Tunnel for some time now and a considerable amount of data has been taken.[1,2] Most of this work has been concerned with cones and disks, which have distinct points at which the cavity separates from the nose, but it was thought worthwhile to extend the investigations to include continuously curving noses with shapes such as spheres and ellipsoids.

As a start in this direction, a number of tests have been made on spheres with attached cavities. The sphere was selected as a convenient shape because of its simplicity, the availability of models already made up, and the possibility of comparing results with those of other investigators. The purpose of the present note is to report the test data taken so far; detailed analysis and comparison will be postponed for a future report.

Experimental Setup

The experiments were performed in the Free Surface Water Tunnel and the measurement techniques were substantially the same as employed in other cavity flow tests in the tunnel.[2] The spheres, which had nominal diameters of 1, 1-1/2 and 2 inches, were supported on a sting and cavity flow was generated by injecting air in the wake (Fig. 1). The vertical position in the working section was varied over several diameters without noticeable effect on the measurements.

The models had a polished finish, but were not specially prepared in any way. They were, in fact, originally made for checking the tunnel turbulence level. A typical close-up photograph is shown in Fig. 2.

Results of Measurements

In these tests only the drag and point of cavity separation were measured at speeds of 16 and 25 fps on the three spheres. The main experimental results are presented in Fig. 3, where C_D, the drag coefficient, is plotted against σ, the cavitation parameter, where these quantities are defined by the formulas given below under "Symbols".

There is some scatter in the drag measurements which, aside from experimental error, may be due either to viscous or surface tension effects. It is not possible to ascertain whether such scale influences exist within the range of the present data, but comparison with other results should prove interesting, although beyond the scope of this report.

The measurements of the point of cavity separation were obtained from photographs such as Fig. 2. It was assumed that the most upstream part of the scalloped line of demarcation corresponds to the actual separation point. The scalloped effect is most likely caused by surface tension, and since it would evidently tend to move the separation point aft, the measured values of the separation angle plotted will most likely be somewhat larger than would be predicted from a perfect fluid theory, such as Armstrong is now developing.[3]

Symbols

C_D, drag coefficient, $C_D = D/\frac{1}{2}\rho V^2 \frac{\pi}{4} d^2$

D, drag force

d, sphere diameter

p_k, pressure in cavity

p_o, pressure in undisturbed stream at elevation of sphere center

V, velocity in undisturbed stream

ρ, density of water

σ, cavitation parameter, $\sigma = (p_o - p_k)/\frac{1}{2}\rho V^2$

φ, cavity separation angle (see Fig. 3).

References

1. O'Neill, J. P., "The Dynamics of Underwater Bodies Running in an Open Cavity", Hydrodynamics Laboratory Report No. M-24.1, Calif. Inst. of Technology, April 1951.

2. Kiceniuk, T., "An Experimental Study of the Hydrodynamic Forces Acting on a Family of Cavity-Producing Conical Bodies of Revolution Inclined to the Flow", Hydrodynamics Laboratory Report No. E-12.17, Calif. Inst. of Technology, June 1954.

3. Armstrong, A. H., "Abrupt and Smooth Separation in Plane and Axisymmetric Cavity Flow", Memo 22/53, Armament Research Establishment, Fort Halstead, Kent, England, December 1953.

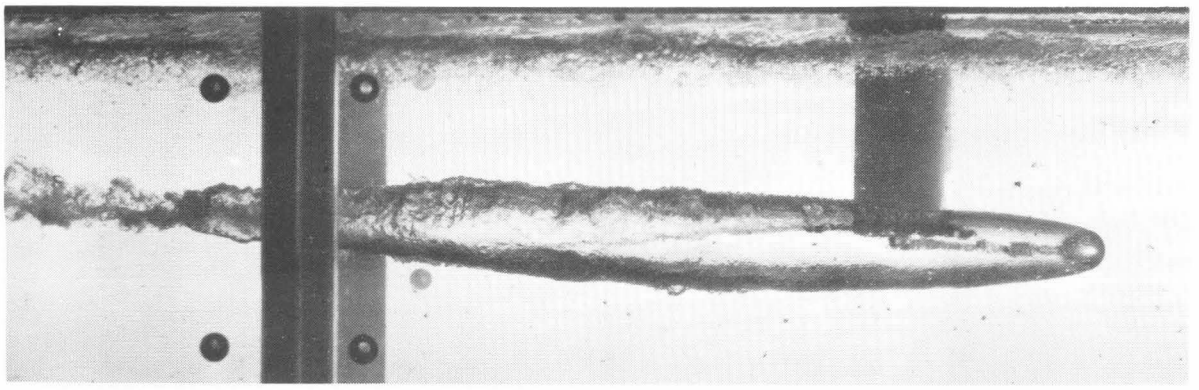

Fig. 1 - Sphere with air cavity in Free Surface Tunnel. Nominal diameter, 1.5 in.; flow velocity, 25 fps; cavitation number, 0.046.

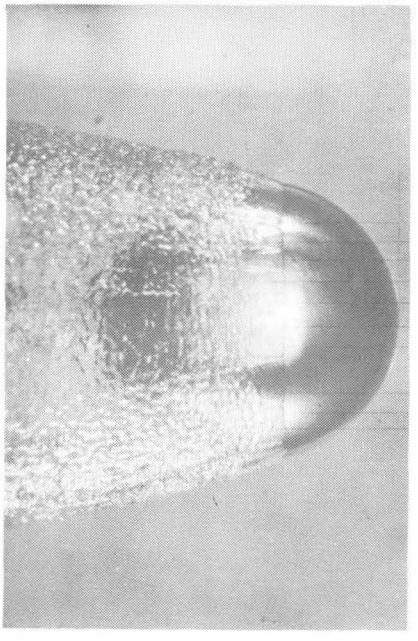

Fig. 2 - Close-up of sphere showing line of cavity separation. Nominal diameter, 1.5 in.; flow velocity, 25 fps; cavitation number, 0.048.

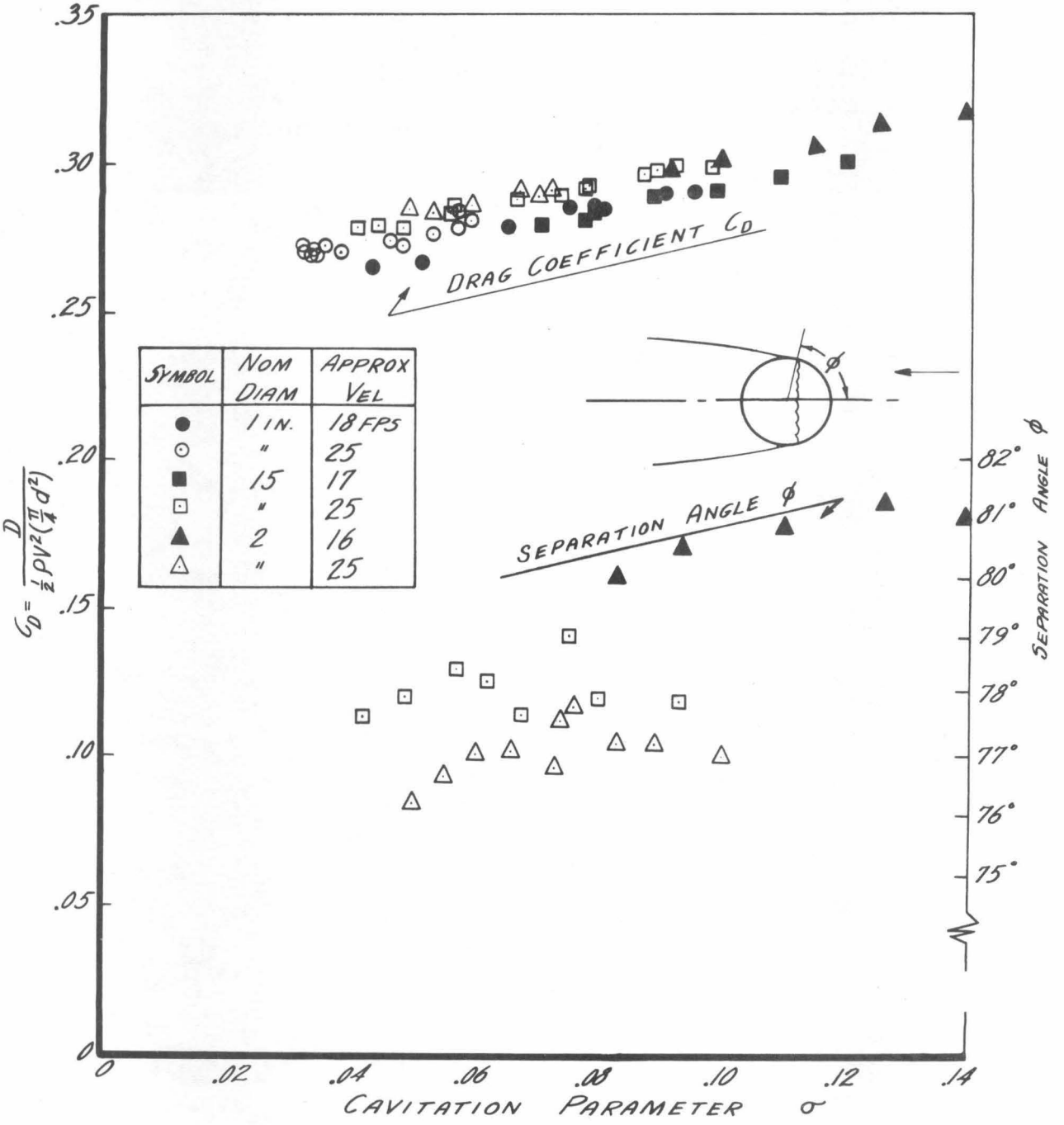

Fig. 3 - Measured drag coefficients and separation angles for spheres with attached air cavities as a function of the cavitation parameter.